

## 13.7: End-of-Chapter Material

### Exercises (Chemical Equilibrium)

1. Define the law of mass action.
2. What is an equilibrium constant for a chemical reaction? How is it constructed?

3. Write the  $K_{eq}$  expression for each reaction.

- a.  $H_2 + Cl_2 \rightleftharpoons 2HCl$
- b.  $NO + NO_2 \rightleftharpoons N_2O_3$

4. Write the  $K_{eq}$  expression for each reaction.

- a.  $C_2H_5OH + NaI \rightleftharpoons C_2H_5I + NaOH$
- b.  $PCl_3 + Cl_2 \rightleftharpoons PCl_5$

5. Write the  $K_P$  expression for each reaction.

- a.  $2H_2(g) + O_2(g) \rightleftharpoons 2H_2O(g)$
- b.  $2H_2O_2(g) \rightleftharpoons 2H_2O(g) + O_2(g)$

6. Write the  $K_P$  expression for each reaction.

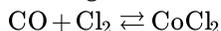
- a.  $CH_4(g) + 2O_2(g) \rightleftharpoons CO_2(g) + 2H_2O(g)$
- b.  $CH_4(g) + 4Cl_2(g) \rightleftharpoons CCl_4(g) + 4HCl(g)$

7. The following reaction is at equilibrium:



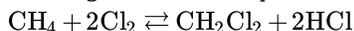
The equilibrium  $[Br_2]$  and  $[PBr_5]$  are 2.05M and 0.55M, respectively. If the  $K_{eq}$  is 1.65, what is the equilibrium  $[PBr_3]$ ?

8. The following reaction is at equilibrium:



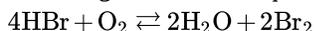
The equilibrium  $[CO]$  and  $[Cl_2]$  are 0.088M and 0.103M, respectively. If the  $K_{eq}$  is 0.225, what is the equilibrium  $[COCl_2]$ ?

9. The following reaction is at equilibrium:



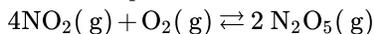
If  $[CH_4]$  is 0.250M,  $[Cl_2]$  is 0.150M, and  $[CH_2Cl_2]$  is 0.175M at equilibrium, what is  $[HCl]$  at equilibrium if the  $K_{eq}$  is 2.30?

10. The following reaction is at equilibrium:

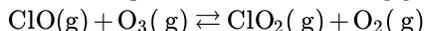


If  $[HBr]$  is 0.100M,  $[O_2]$  is 0.250M, and  $[H_2O]$  is 0.0500M at equilibrium, what is  $[Br_2]$  at equilibrium if the  $K_{eq}$  is 0.770?

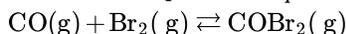
11. Write the  $K_P$  expression for the following gas-phase reaction:



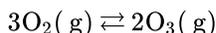
12. Write the  $K_P$  expression for the following gas-phase reaction:



13. What is the equilibrium partial pressure of  $COBr_2$  if the equilibrium partial pressures of  $CO$  and  $Br_2$  are 0.666 atm and 0.235 atm and the  $K_P$  for this equilibrium is 4.08?



14. What is the equilibrium partial pressure of  $O_3$  if the equilibrium partial pressure of  $O_2$  is 0.0044 atm and  $K_P$  for this equilibrium is 0.00755?



15. Calculate the  $K_P$  for this reaction at 298 K if the  $K_{eq} = 1.76 \times 10^{-3}$ .  
 $3O_2(g) \rightleftharpoons 2O_3(g)$
16. Calculate the  $K_P$  for this reaction at 310 K if the  $K_{eq} = 6.22 \times 10^3$ .  
 $4NO_2(g) + O_2(g) \rightleftharpoons 2N_2O_5(g)$
17. Calculate the  $K_{eq}$  for this reaction if the  $K_P = 5.205 \times 10^{-3}$  at  $660^\circ\text{C}$ .  
 $CO(g) + F_2(g) \rightleftharpoons COF_2(g)$
18. Calculate the  $K_{eq}$  for this reaction if the  $K_P = 78.3$  at  $100^\circ\text{C}$ .  
 $4HCl(g) + O_2(g) \rightleftharpoons 2H_2O(g) + 2Cl_2(g)$
19. Write the correct  $K_{eq}$  expression for this reaction.  
 $NaOH(aq) + HCl(aq) \rightleftharpoons NaCl(aq) + H_2O(l)$
20. Write the correct  $K_{eq}$  expression for this reaction.  
 $AgNO_3(aq) + NaCl(aq) \rightleftharpoons AgCl(s) + NaNO_3(aq)$
21. Write the correct  $K_P$  expression for this reaction.  
 $CaCO_3(s) \rightleftharpoons CaO(s) + CO_2(g)$
22. Write the correct  $K_P$  expression for this reaction.

### Answers

1. the relationship between the concentrations of reactants and products of a chemical reaction at equilibrium

3. a.  $K_{eq} = \frac{[HCl]^2}{[H_2][Cl_2]}$

b.  $K_{eq} = \frac{[N_2O_3]}{[NO][NO_2]}$

5. a.  $K_P = \frac{P_{H_2O}^2}{P_{H_2}^2 P_{O_2}}$

b.  $K_P = \frac{P_{H_2O}^2 P_{O_2}}{P_{H_2O_2}^2}$

7. 0.163M

9. 0.272M

11.  $K_P = \frac{P_{N_2O_5}^2}{P_{NO_2}^4 P_{O_2}}$

13. 0.639 atm

15.  $7.20 \times 10^{-5}$

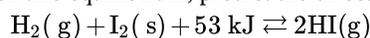
17.  $K_{eq} = 3.98 \times 10^{-1}$

19.  $K_{eq} = \frac{[NaCl]}{[NaOH][HCl]}$

21.  $K_P = P_{CO}$

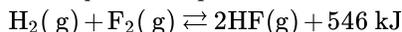
### Exercises (Le Chatelier's principle)

- Define Le Chatelier's principle.
- What is meant by a stress? What are some of the ways an equilibrium can be stressed?
- Given this equilibrium, predict the direction of shift for each stress.



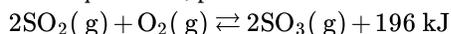
- a. decreased temperature
- b. increased pressure
- c. removal of HI

4. Given this equilibrium, predict the direction of shift for each stress.



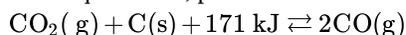
- a. increased temperature
- b. addition of  $\text{H}_2$
- c. decreased pressure

5. Given this equilibrium, predict the direction of shift for each stress.



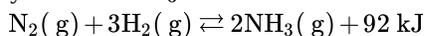
- a. removal of  $\text{SO}_3$
- b. addition of  $\text{O}_2$
- c. decreased temperature

6. Given this equilibrium, predict the direction of shift for each stress listed.



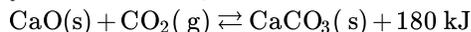
- a. addition of CO
- b. increased pressure
- c. addition of a catalyst

7. The synthesis of  $\text{NH}_3$  uses this chemical reaction.



Identify three stresses that can be imposed on the equilibrium to maximize the amount of  $\text{NH}_3$ .

8. The synthesis of  $\text{CaCO}_3$  uses this chemical reaction.



Identify three stresses that can be imposed on the equilibrium to maximize the amount of  $\text{CaCO}_3$ .

### Answers

1. When an equilibrium is stressed, the equilibrium shifts to minimize that stress.

3.

- a. toward reactants
- b. toward reactants
- c. toward products

5.

- a. toward products
- b. toward products
- c. toward products

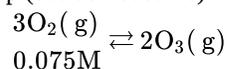
7. increased pressure, decreased temperature, removal of  $\text{NH}_3$

### Exercises (Calculating Equilibrium Constant Values)

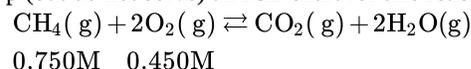
1. Describe the three parts of an ICE chart.

2. What is the relationship between the equilibrium row in an ICE chart and the other two rows?

3. Set up (but do not solve) an ICE chart for this reaction, given the initial conditions.

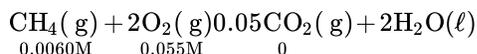


4. Set up (but do not solve) an ICE chart for this reaction, given the initial conditions.

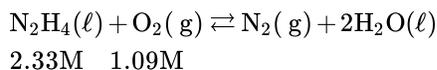


5. Given that pure solids and liquids do not appear in  $K_{\text{eq}}$  expressions, set up the ICE chart for this reaction, given the initial

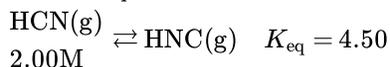
conditions.



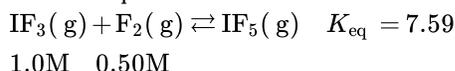
6. Given that pure solids and liquids do not appear in  $K_{\text{eq}}$  expressions, set up the ICE chart for this reaction, given the initial conditions.



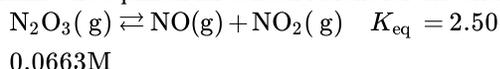
7. Determine the equilibrium concentrations for this chemical reaction with the given  $K_{\text{eq}}$ .



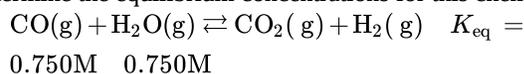
8. Determine the equilibrium concentrations for this chemical reaction with the given  $K_{\text{eq}}$ .



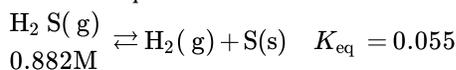
9. Determine the equilibrium concentrations for this chemical reaction with the given  $K_{\text{eq}}$ .



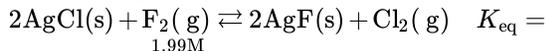
10. Determine the equilibrium concentrations for this chemical reaction with the given  $K_{\text{eq}}$ .



11. Determine the equilibrium concentrations for this chemical reaction with the given  $K_{\text{eq}}$ .



12. Determine the equilibrium concentrations for this chemical reaction with the given  $K_{\text{eq}}$ .



## Answers

1. I = initial concentrations; C = change in concentrations; E = equilibrium concentrations

3.

	$3\text{O}_2$	$\rightleftharpoons$	$2\text{O}_3$
I	0.075		0
C	-3 x		+2 x
E	0.075-3 x		+2 x

5.

	$\text{CH}_4$	+	$2\text{O}_2$	$\rightleftharpoons$	$\text{CO}_2$	+	$2\text{H}_2\text{O}$
I	0.0060		0.055		0		0
C	-x		-2 x		+x		-
E	0.0060-x		.055-2 x		+x		-

7.  $[\text{HCN}] = 0.364M$ ;  $[\text{HNC}] = 1.64M$

9.  $[\text{N}_2\text{O}_3] = 0.0017M$ ;  $[\text{NO}] = [\text{NO}_2] = 0.0646M$

11.  $[\text{H}_2\text{S}] = 0.836M$ ;  $[\text{H}_2] = 0.046M$

## Exercises (Some Special Types of Equilibria)

1. Explain the difference between the  $K_{\text{eq}}$  and the  $K_{\text{sp}}$ .

2. Explain the difference between the  $K_a$  and the  $K_b$ .
3. Write the balanced chemical equation that represents the equilibrium between  $\text{HF}(\text{aq})$  as reactants and  $\text{H}^+(\text{aq})$  and  $\text{F}^-(\text{aq})$  as products.
4. Write the balanced chemical equation that represents the equilibrium between  $\text{CaF}_2(\text{s})$  as reactants and  $\text{Ca}^{2+}(\text{aq})$  and  $\text{F}^-(\text{aq})$  as products.
5. Assuming that all species are dissolved in solution, write the  $K_{\text{eq}}$  expression for the chemical equation in Exercise 3.
6. Noting the phase labels, write the  $K_{\text{sp}}$  expression for the chemical equation in Exercise 4.
7. Determine the concentrations of all species in the ionization of  $0.100\text{M HClO}_2$  in  $\text{H}_2\text{O}$ . The  $K_{\text{a}}$  for  $\text{HClO}_2$  is  $1.1 \times 10^{-2}$ .
8. Determine the concentrations of all species in the ionization of  $0.0800\text{M HCN}$  in  $\text{H}_2\text{O}$ . The  $K_{\text{a}}$  for  $\text{HCN}$  is  $6.2 \times 10^{-10}$ .
9. Determine the pH of a  $1.00\text{M}$  solution of  $\text{HNO}_2$ . The  $K_{\text{a}}$  for  $\text{HNO}_2$  is  $5.6 \times 10^{-4}$ .
10. Determine the pH of a  $3.35\text{M}$  solution of  $\text{HC}_2\text{H}_3\text{O}_2$ . The  $K_{\text{a}}$  for  $\text{HC}_2\text{H}_3\text{O}_2$  is  $1.8 \times 10^{-5}$ .
11. Write the chemical equations and  $K_{\text{a}}$  expressions for the stepwise dissociation of  $\text{H}_3\text{PO}_4$ .
12. Write the chemical equations and  $K_{\text{a}}$  expressions for the stepwise dissociation of  $\text{H}_3\text{C}_6\text{H}_5\text{O}_7$ .
13. If the  $K_{\text{a}}$  for  $\text{HNO}_2$  is  $5.6 \times 10^{-4}$ , what is the  $K_{\text{b}}$  for  $\text{NO}_2^-(\text{aq})$ ?
14. If the  $K_{\text{a}}$  for  $\text{HCN}$  is  $6.2 \times 10^{-10}$ , what is the  $K_{\text{b}}$  for  $\text{CN}^-(\text{aq})$ ?
15. What is  $[\text{OH}^-]$  in a solution whose  $[\text{H}^+]$  is  $3.23 \times 10^{-6}\text{M}$ ?
16. What is  $[\text{OH}^-]$  in a solution whose  $[\text{H}^+]$  is  $9.44 \times 10^{-11}\text{M}$ ?
17. What is  $[\text{H}^+]$  in a solution whose  $[\text{OH}^-]$  is  $2.09 \times 10^{-2}\text{M}$ ?
18. What is  $[\text{H}^+]$  in a solution whose  $[\text{OH}^-]$  is  $4.07 \times 10^{-7}\text{M}$ ?
19. Write the balanced chemical equation and the  $K_{\text{sp}}$  expression for the slight solubility of  $\text{Mg}(\text{OH})_2(\text{s})$ .
20. Write the balanced chemical equation and the  $K_{\text{sp}}$  expression for the slight solubility of  $\text{Fe}_2(\text{SO}_4)_3(\text{s})$ .
21. What are  $[\text{Sr}^{2+}]$  and  $[\text{SO}_4^{2-}]$  in a saturated solution of  $\text{SrSO}_4(\text{s})$ ? The  $K_{\text{sp}}$  of  $\text{SrSO}_4(\text{s})$  is  $3.8 \times 10^{-4}$ .
22. What are  $[\text{Ba}^{2+}]$  and  $[\text{F}^-]$  in a saturated solution of  $\text{BaF}_2(\text{s})$ ? The  $K_{\text{sp}}$  of  $\text{BaF}_2(\text{s})$  is  $1.8 \times 10^{-7}$ .
23. What are  $[\text{Ca}^{2+}]$  and  $[\text{OH}^-]$  in a saturated solution of  $\text{Ca}(\text{OH})_2(\text{s})$ ? The  $K_{\text{sp}}$  of  $\text{Ca}(\text{OH})_2(\text{s})$  is  $5.0 \times 10^{-6}$ .
24. What are  $[\text{Pb}^{2+}]$  and  $[\text{I}^-]$  in a saturated solution of  $\text{PbI}_2$ ? The  $K_{\text{sp}}$  for  $\text{PbI}_2$  is  $9.8 \times 10^{-9}$ .

### Answers

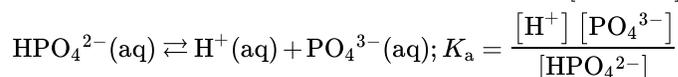
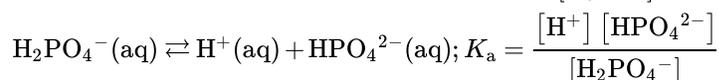
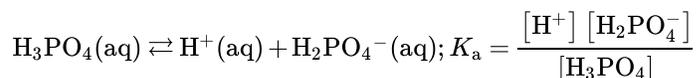
1. The  $K_{\text{sp}}$  is a special type of the  $K_{\text{eq}}$  and applies to compounds that are only slightly soluble.
3.  $\text{HF}(\text{aq}) \rightleftharpoons \text{H}^+(\text{aq}) + \text{F}^-(\text{aq})$

$$5. K_{\text{eq}} = \frac{[\text{H}^+][\text{F}^-]}{[\text{HF}]}$$

$$7. [\text{HClO}_2] = 0.0719\text{M}; [\text{H}^+] = [\text{ClO}_2^-] = 0.0281\text{M}$$

$$9. 1.63$$

11.



$$13. 1.8 \times 10^{-11}$$

$$15. 3.10 \times 10^{-9}\text{M}$$

$$17. 4.78 \times 10^{-13}\text{M}$$



$$21. [\text{Sr}^{2+}] = [\text{SO}_4^{2-}] = 1.9 \times 10^{-2}\text{M}$$

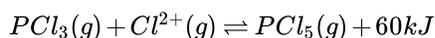
$$23. [\text{Ca}^{2+}] = 0.011\text{M}; [\text{OH}^-] = 0.022\text{M}$$

### Additional Exercises

1. What is the relationship between the  $K_{\text{SP}}$  expressions for a chemical reaction and its reverse chemical reaction?

2. What is the relationship between the  $K_{\text{W}}$  value for  $\text{H}_2\text{O}$  and its reverse chemical reaction?

3. For the equilibrium



list four stresses that serve to increase the amount of  $\text{PCl}_5$ .

4. For the equilibrium

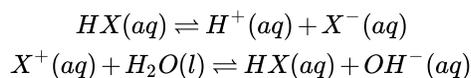


list four stresses that serve to increase the amount of  $\text{NO}_2$ .

5. Does a very large  $K_{\text{eq}}$  favor the reactants or the products? Explain your answer.

6. Is the  $K_{\text{eq}}$  for reactions that favor reactants large or small? Explain your answer.

7. Show that  $K_{\text{a}} \times K_{\text{b}} = K_{\text{W}}$  by determining the expressions for these two reactions and multiplying them together.



8. Is the conjugate base of a strong acid weak or strong? Explain your answer.

9. What is the solubility in moles per liter of AgCl? Use data from Table 13.7.2- Solubility Product Constants for Slightly Soluble Ionic Compounds.
10. What is the solubility in moles per liter of Ca(OH)<sub>2</sub>? Use data from Table 13.7.2- Solubility Product Constants for Slightly Soluble Ionic Compounds.
11. Under what conditions is  $K_{\text{eq}} = K_{\text{p}}$ ?
12. Under what conditions is  $K_{\text{eq}} > K_{\text{p}}$  when the temperature is 298 K?
13. What is the pH of a saturated solution of Mg(OH)<sub>2</sub>? Use data from Table 13.7.2- Solubility Product Constants for Slightly Soluble Ionic Compounds.
14. What are the pH and the pOH of a saturated solution of Fe(OH)<sub>3</sub>? The  $K_{\text{sp}}$  of Fe(OH)<sub>3</sub> is  $2.8 \times 10^{-39}$ .
15. For a salt that has the general formula MX, an ICE chart shows that the  $K_{\text{sp}}$  is equal to  $x^2$ , where  $x$  is the concentration of the cation. What is the appropriate formula for the  $K_{\text{sp}}$  of a salt that has a general formula of MX<sub>2</sub>?
16. Referring to Exercise 15, what is the appropriate formula for the  $K_{\text{sp}}$  of a salt that has a general formula of M<sub>2</sub>X<sub>3</sub> if the concentration of the cation is defined as  $2x$ , rather than  $x$ ?
17. Consider a saturated solution of PbBr<sub>2</sub>(s). If  $[\text{Pb}^{2+}]$  is  $1.33 \times 10^{-5}$  M, find each of the following.
  - a.  $[\text{Br}^-]$
  - b. the  $K_{\text{sp}}$  of PbBr<sub>2</sub>(s)
18. Consider a saturated solution of Pb<sub>3</sub>(PO<sub>4</sub>)<sub>2</sub>(s). If  $[\text{Pb}^{2+}]$  is  $7.34 \times 10^{-14}$  M, find each of the following.
  - a.  $[\text{PO}_4^{3-}]$
  - b. the  $K_{\text{sp}}$  of Pb<sub>3</sub>(PO<sub>4</sub>)<sub>2</sub>(s)

### Answers

1. They are reciprocals of each other.
3. increase the pressure; decrease the temperature; add PCl<sub>3</sub>; add Cl<sub>2</sub>; remove PCl<sub>5</sub>
5. favor products because the numerator of the ratio for the  $K_{\text{eq}}$  is larger than the denominator
9.  $1.3 \times 10^{-5}$  mol/L
11.  $K_{\text{eq}} = K_{\text{p}}$  when the number of moles of gas on both sides of the reaction is the same.
13. 10.35
15.  $4x^3$
17. a.  $2.66 \times 10^{-5}$  M  
b.  $9.41 \times 10^{-15}$

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